

IMAGE ANALYSIS APPLIED TO SLICES OF HISTORY

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INTRODUCTION

During the last 10 years, TASC has undertaken several digital image enhancement projects based on nondestructive evaluation (NDE) applications. Most of these projects involved analyzing NDE imagery to determine why a critical part failed to operate as expected, or trying to recover from a failure which degraded NDE imagery or made it difficult to obtain. Examples include our studies of the Inertial Upper Stage nozzle nosecap following the unsuccessful launch of a Tracking Data Relay Satellite in the summer of 1983 [1] and our development of a video data image processing system to enhance, in real time, unevenly lit, poor-contrast signals from within the contaminated Number 2 reactor vessel at Three Mile Island [2].

This paper describes another image enhancement project at TASC, but this effort involved a rather unique application. The problem was to determine the contents of a 100-year old time capsule before it was opened.

The organization of this paper is as follows. First, the origin of the time capsule is discussed. Next, the use of computed tomography at NASA's Marshall Space Flight Center to scan the interior of the capsule and provide a first-look at its contents is described. The enhancement of the resultant tomograms at TASC is then presented. We show how basic signal processing methods were used to improve image quality using some interesting examples from the imagery of the capsule. The highlights of the time capsule opening are summarized and the paper concludes with a discussion of how NDE techniques were used to advantage in this application.

BACKGROUND

In the fall of 1988, Benjamin P. Field V asked the National Geographic Society to observe the opening of his time capsule. The time capsule was a box about 20 inches long, 15 inches wide, and 8 inches deep with the words "OPEN IN 1989"

inscribed on it. It was rumored to contain mementoes from the Centennial Celebration of George Washington's inauguration which took place in New York City on April 30, 1889, and possibly even contain objects from that first inauguration [3]. In order to verify the authenticity of Ben's story and to ensure that whatever was in the box would not be damaged during the opening, the Society arranged for the application of NDE techniques to the sealed box.

On January 19 and 20, 1989, laboratory personnel at NASA's Marshall Space Flight Center in Huntsville, Alabama scanned the box using the Advanced Computed Tomography Inspection System (ACTIS). This is a translate-rotate (second-generation) x-ray computed tomography (CT) imaging system used in the inspection of spacecraft and associated propulsion system components. The ACTIS allows the distance between source and detectors to be varied to optimize the geometry for each test object. Three radiation sources spanning the energy range from 150 keV to 15 MeV accommodate the scanning of a variety of material thicknesses and densities, while a large number of focusing detectors positioned in a dense array contributes to a high x-ray collection efficiency. The variable geometry, multiple energy sources, and multiple focusing detectors allow the user to optimize the spatial, density, and temporal resolution of the scanner for each application [4,5].

Scans were taken at a beam energy of 2 MeV with the box positioned on the ACTIS turntable so that its 20 by 15 inch dimensions were at the top and bottom. Cross-sectional slices were taken horizontally from top to bottom of the box at a nominal 4-mm spacing. The integration thickness of each slice was also 4 mm. The spacing between slice centers was reduced to 1 or 2 mm in areas of special interest. The reconstruction field of view was slightly greater than the larger horizontal dimension of the box and most of the resulting tomograms were sized at 1024 by 1024 pixels. The ACTIS was also capable of producing "zoom reconstructions" of enhanced resolution at 2048 by 2048 pixels. At the end of the scanning session, approximately 45 tomograms were available for closer examination.

Review of the tomograms at NASA/Marshall provided the first clear look at the contents of the time capsule. In general, observable detail was very good. The capsule consisted of an outer galvanized cover, an inner wooden box made of pine or cedar boards nailed together over an inner metal lining. Woodgrain, planking, several metallic objects appearing to be medallions, pins, or coins, and a number of metal/wood discontinuities were noted. Artifacts were only evident around the nails holding the planks of the box together. These nails were generally the smallest high-density contrast objects observed.

The majority of the contents was printed material, precisely fitted in the box, but mostly still undecipherable except for size and shape details. Legends on some of the items were observed, but significant detailed information about the nature and contents of the documents could not be recovered. An artist's rendering of the interior of Ben Field's time capsule was prepared upon completion of the scanning process. This picture, which reflected the study team's understanding of the box's contents, appeared in the May issue of National Geographic [3].

ENHANCEMENT TECHNIQUES AND EXAMPLES

Enhancement of selected tomograms was performed in the Computing Technology Center at TASC. Our goal was to bring out more detail in the images which

were judged to be most interesting by the scanning team at NASA/Marshall. The digital images were stored with a resolution of 12 bits per pixel and this resolution was maintained throughout the processing. Rescaling was only necessary for display on our 256 gray level, 512 by 512 pixel video display.

The techniques which best satisfied our goal included an interactive contrast stretch, adaptive histogram equalization, a sharpening procedure we call unsharp masking edge detection, and a technique which involved combining nearby slices from the capsule. Details of each of these techniques are discussed below and selected enhancement results are shown.

The first technique is an interactive contrast stretch. It is accomplished by defining a piecewise linear function which maps the pixel values to desired displayed intensities according to the equation

$$g'(x,y) = f[g(x,y)] \quad (1)$$

where $g'(x,y)$ is the displayed intensity at coordinate (x,y) , $f[\]$ is the mapping function, and $g(x,y)$ is the pixel value at (x,y) . For example, if the pixels with initial intensities between 0 and 64 are remapped ("stretched") to extend over the range 0 to 128 (and the pixels with original intensities greater than 64 are adjusted accordingly), the dark region of the image brightens. Similarly, stretching the intensities associated with the lighter region darkens the image. This technique was used to initially preview the images and then as the final enhancement step for each image.

The second technique is adaptive histogram equalization. The original pixel intensity values are remapped so that each gray level occurs about the same number of times over the full intensity range. Thus, after application of this technique to an image whose original distribution of intensities covers a very narrow range, the resulting histogram is spread across the full intensity range.

By using an adaptive technique [6], the equalization parameters automatically adjust to each local area of the image. This allows contrast in the darker areas of an image to be increased without washing out details resident in the lighter areas. Equalization is performed using all of the pixels within a sliding window to enhance the one pixel currently in the center of the window. This technique is computationally intensive — using a 31 by 31 pixel window on a 512 by 512 pixel image requires about 25 million floating point operations. This technique was employed on those images containing lettering and/or numbers, such as that shown in Fig. 1 which represents a weekly calendar. On the right of this figure is a scanned photograph of the actual item which was recovered from the box upon its opening. The ability to extract any lettering on a document contained in the sealed box is a significant accomplishment of the scanning and enhancement processes.

A difficulty which was encountered in analyzing the contents of the box, particularly the small metallic objects, was the slanted position of these objects with respect to the orientation of their tomographic slices. As a consequence, different parts of each object were imaged with varying levels of contrast. Moreover, there was a wide variation in dynamic range across the face of each object in the image. Of most interest were the fine details resident in the variations about a nominal intensity value which changed slowly across the image as more or less of the object of interest coincided with the tomographic slice being viewed.

A two-step deblurring approach was used to enhance this imagery. Denoting the image intensity at pixel coordinate (x,y) by $I(x,y)$,



Fig. 1. Adaptive histogram equalization example.

$$I(x,y) = B(x,y) + D(x,y) \quad (2)$$

where $B(x,y)$ and $D(x,y)$ are the intensities associated with the basic shape and fine details of the object, respectively. Since we did not have accurate geometric information about the object's position, a circularly symmetric gaussian kernel with a large variance was used to filter the image and estimate $B(x,y)$. Because $D(x,y)$ varied rapidly compared with $B(x,y)$, filtering attenuated the fine details while retaining a good estimate of the basic object. Next this filtered estimate $I'(x,y)$ was differenced with the original image to obtain

$$D'(x,y) = I(x,y) - I'(x,y) \quad (3)$$

where $D'(x,y)$ is an estimate of $D(x,y)$ and depicts the fine details which had been obscured in the original image. This sharpened image was then contrast stretched to occupy the full dynamic range of the video display. The net effect of this processing was to perform a high-pass filtering operation on the image with a very narrow stopband near the zero frequency. This type of processing is common in image enhancement and is a digital form of the unsharp masking photographic process [7].

Figure 2 contains an example of an image which was enhanced using our unsharp masking edge detection technique. The object of interest in this image is a metal disk enclosed in a presentation case. The enhancement reveals a clearer profile of our first president.

Another observation which was apparent upon examining the images was that certain objects appeared in multiple slices and that each slice highlighted different details of the same object. Therefore, a new composite image was created by including all of the details from the individual slices. This composite sum image was then enhanced using our sharpening edge detector and then the interactive contrast stretch technique.

An example which highlights the technique of combining multiple slices is shown in Fig. 3. Cutouts of the object of interest from the original images appear in the left top and bottom (with their associated NASA/Marshall file names). The sum image rescaled to display in 256 levels is shown in the left middle picture. After sharpening, individual star-like points and a person's profile are now much clearer. The contrast stretched result is shown on the right side.

Identification of the object depicted in Fig. 3 was made by Ben Field V during a visit to TASC. The object was a commemorative pin issued for the Washington in-

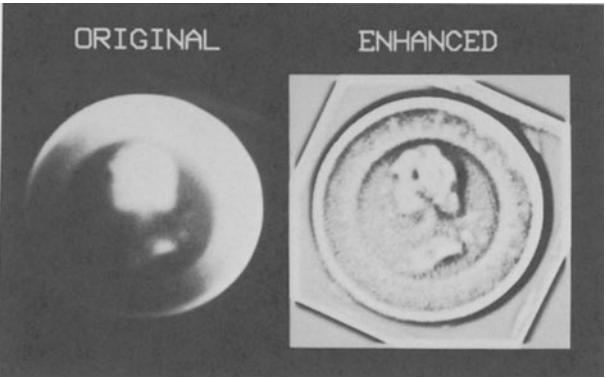


Fig. 2. Unsharp masking edge detection example .

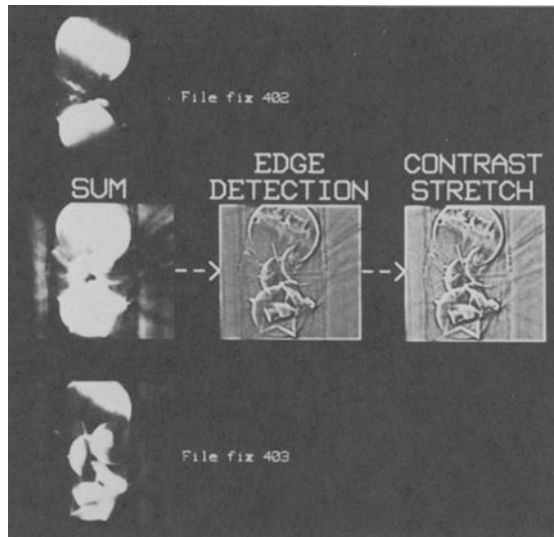


Fig. 3. Combination of nearby slices — example one .



Fig. 4. A commemorative pin from the time capsule .

auguration centennial. This pin was pictured in a catalog of political memorabilia at the Smithsonian Institution. Figure 4 shows the enhanced version next to a scanned photograph of the pin.

A second example showing the effect of the slice combination technique is shown in Fig. 5. The object of interest is a medallion with the markings of a horseman with star-like objects around the perimeter along with two other unique insignia. Details of the medallion were discovered in three separate images. An image of the composite sum (rescaled for display), the sharpened result, and the final contrast stretched result are all included for comparison with the details evident in the three original slices (identified by their NASA/Marshall file names).

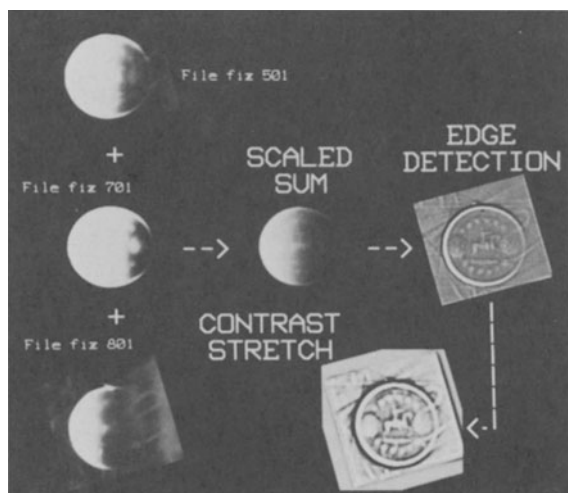


Fig. 5. Combination of nearby slices — example two .

SUMMARY

The time capsule was opened on April 4, 1989 at the Washington D.C. headquarters of the National Geographic Society. Highlights of the opening, along with some background material on Benjamin P. Field II and scenes from NASA/Marshall and TASC, were televised in a National Geographic Explorer special on WTBS on April 30, 1989. Furthermore, the September issue of National Geographic contained an article describing the contents of Ben Field's time capsule [8]. The opening, unpacking, cataloging, and examination spanned seven hours. Newspapers, magazines, family photographs, hymn books, a personal journal, commemorative pins and medallions from the 1889 Centennial, and even the coins Ben Field II had in his pocket during the celebration were recovered from the time capsule.

This NDE work served as an important aid to verify the authenticity of the time capsule and to determine an appropriate level of commitment by the National Geographic Society. In addition, the imagery proved quite useful for guiding the opening and for providing the archivists with prior information about the types of materials they would be handling.

Our enhancement results could not have been generated without the cooperation of several dedicated individuals and responsive organizations. Included in this list are the National Geographic Society, NASA Marshall Space Flight Center, and PIXAR who generated a three-dimensional rendering of the time capsule on their graphics processor.

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